

ALUMINUM SMELTING -
PROCESS DESCRIPTION

4. PROCESS DESCRIPTION

4.1 PRIMARY ALUMINUM REDUCTION ¹⁻⁵

All primary aluminum in the United States is produced by electrolytic reduction of alumina (Al_2O_3)--the Hall-Heroult process. Alumina, an intermediate product, is produced by the Bayer process from bauxite, a naturally occurring ore of hydrous aluminum oxides and hydroxides containing 45 to 55 percent Al_2O_3 . The production of alumina and the electrolytic reduction of alumina to aluminum are seldom accomplished at the same geographical location.

Alumina is shipped to the reduction plant where it is reduced to aluminum and oxygen by direct electric current (Figure 4-1). This reduction is carried out in shallow rectangular cells (pots) made of carbon-lined steel with carbon blocks that are suspended above and extend down into the pot (Figure 4-2). The pots and carbon blocks serve as cathodes and anodes, respectively, for the electrolytical process.

Cryolite, a double fluoride salt of sodium and aluminum (Na_3AlF_6), serves as an electrolyte and a solvent for alumina. Alumina is added to and dissolves in the molten cryolite bath. The cells are heated and operated between 950° and $1,000^{\circ}\text{C}$ with heat that results from resistance between the electrodes. During the reduction process, the aluminum is deposited at the cathode where, because of its heavier weight (2.3 g/cm^3 versus 2.1 g/cm^3), it

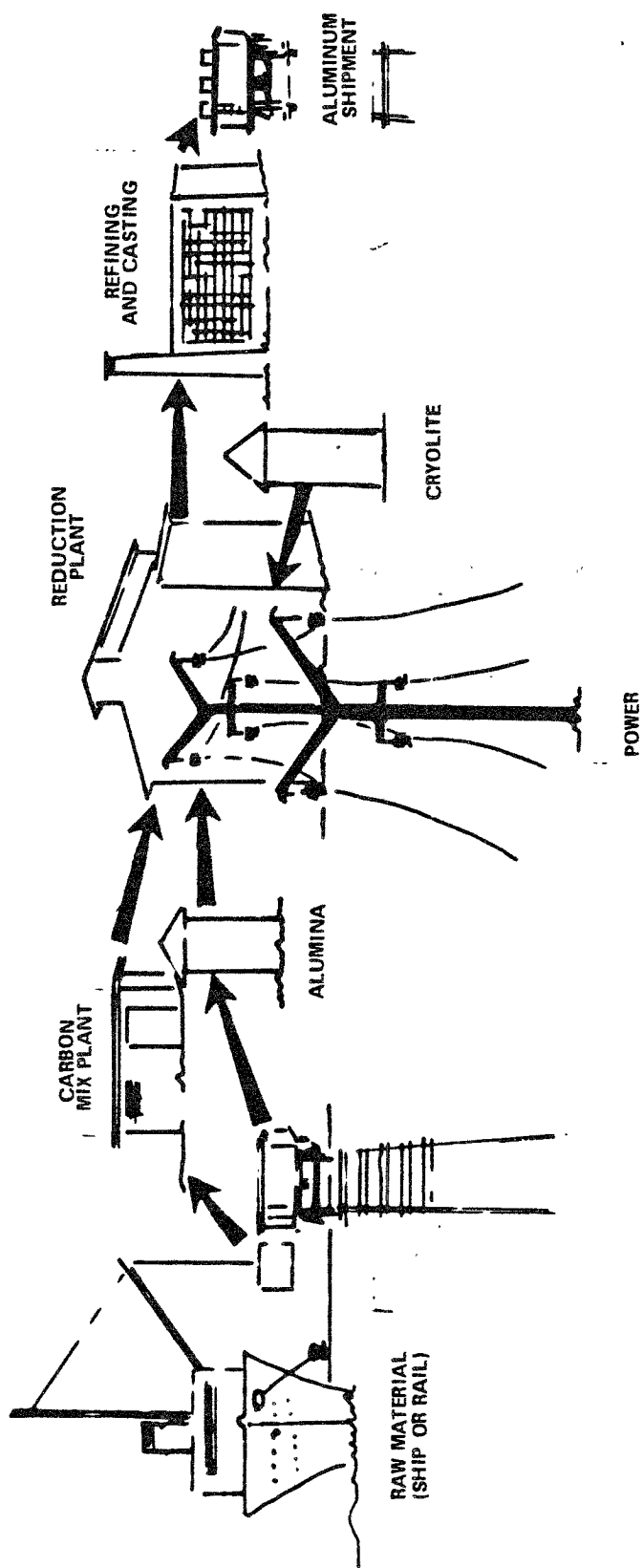


Figure 4-1. Aluminum reduction process.

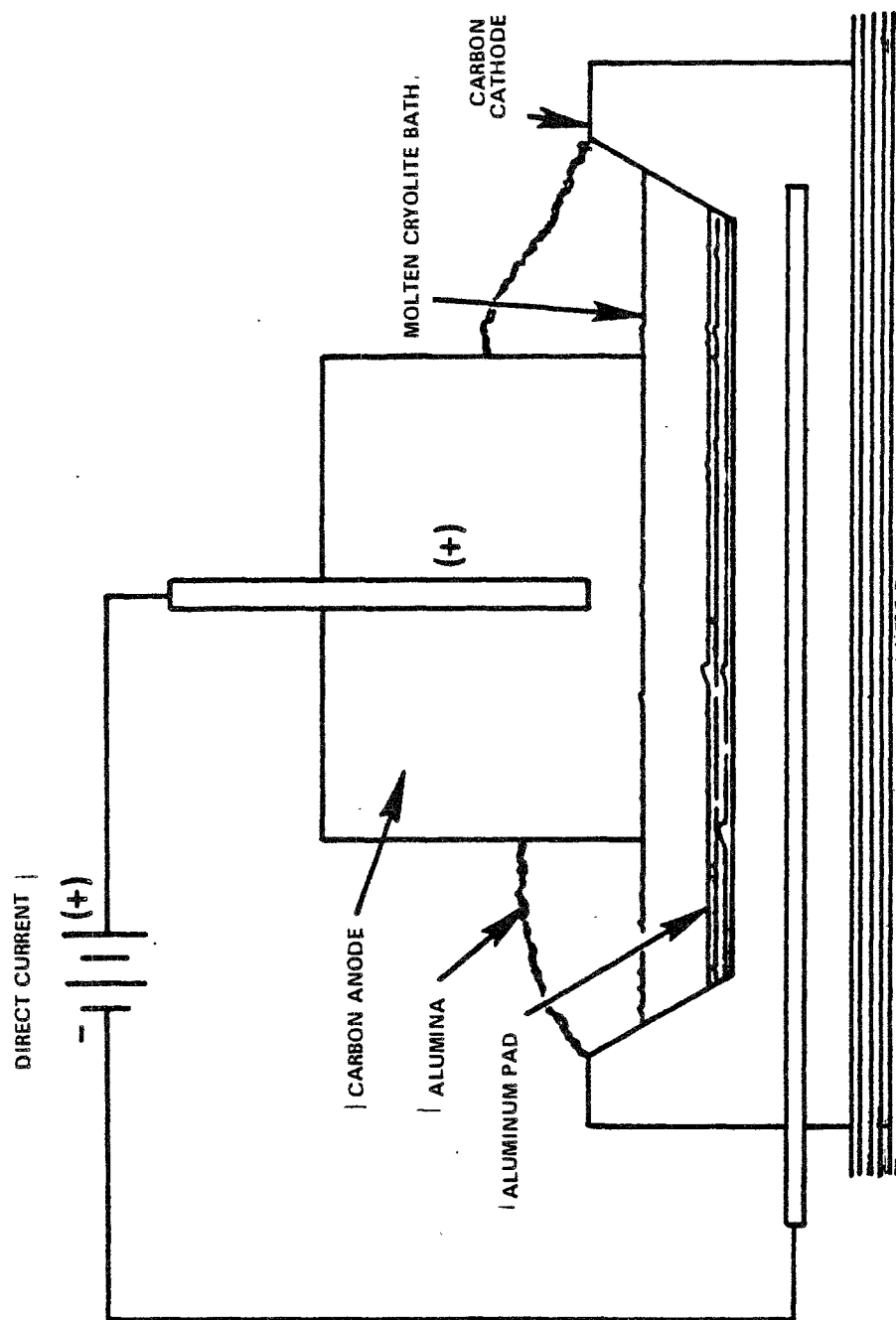


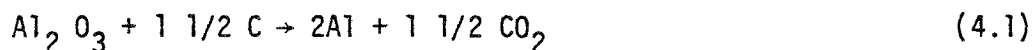
Figure 4-2. Aluminum reduction cell diagram.

remains as a molten metal layer underneath the cryolite. The cryolite bath thus also protects the aluminum from the atmosphere. The byproduct oxygen migrates to and combines with the consumable carbon anode to form carbon dioxide and carbon monoxide, which continually evolve from the cell.

Alumina and cryolite are periodically added to the bath to replenish material that is removed or consumed in normal operation. The weight ratio of sodium fluoride (NaF) to aluminum fluoride (AlF_3) in cryolite is 1.50. However, it has been found that adding excess AlF_3 to reduce the bath ratio to 1.30 to 1.45⁶ will increase cell current efficiency and lower the bath melting point permitting lower operating temperatures. Fluorspar, or calcium fluoride, may also be added to lower the bath melting point.

Periodically, the molten aluminum is siphoned or "tapped" from beneath the cryolite bath, moved in the molten state to holding furnaces in the casting area, and fluxed to remove trace impurities. The product aluminum is later tapped from the holding furnaces and cast into ingots or billets to await further processing or shipped molten in insulated ladles.

The reaction:



absorbs 261.9 kcal per gram mole of alumina reacted at 1000°F, which is equivalent to 2.56 kilowatt-hours (kwh) of energy per pound of aluminum produced.⁷ In actual practice, however, some energy is used to bring the reactants (including the carbon anode) up to temperature

and is lost in the byproduct gas stream, with the tapped aluminum, and to the building. The latter occurs principally through the low temperature heat leak provided by the molten aluminum layer beneath the cryolite bath. A small portion of the molten aluminum mixes with the bath and is carried to the anode where it is oxidized back to alumina, reducing some of the carbon dioxide to carbon monoxide. (Much of the hot carbon monoxide is oxidized back to carbon dioxide upon contacting air.) This reduction absorbs additional energy, and practically the total cell energy requirement is from 6 to 9 kwh per pound of aluminum produced. Furthermore, although the stoichiometric carbon requirement by equation (4.1) is 0.33 pound per pound of aluminum produced, the reduction of carbon dioxide to carbon monoxide increases the carbon requirement to about 0.50 pound per pound of aluminum produced.^{7,8}

A typical late design cell may operate at 100,000 amperes and 4.5 volts (450 kilowatts), producing 1540 pounds of aluminum per day for an energy consumption of approximately 7 kwh per pound of aluminum produced.⁹

A large number of cells are linked together electrically in series to form a potline, the basic production unit of the reduction plant. The potline may be housed in one or two long ventilated buildings called potrooms. A typical plan view of a potroom in schematic form is shown in Figure 4-3. A typical elevation might be as shown in Figure 4-4. The pots may be arranged end to end or side by side. The roof "monitor" or ventilator shown in Figure 4-4 usually

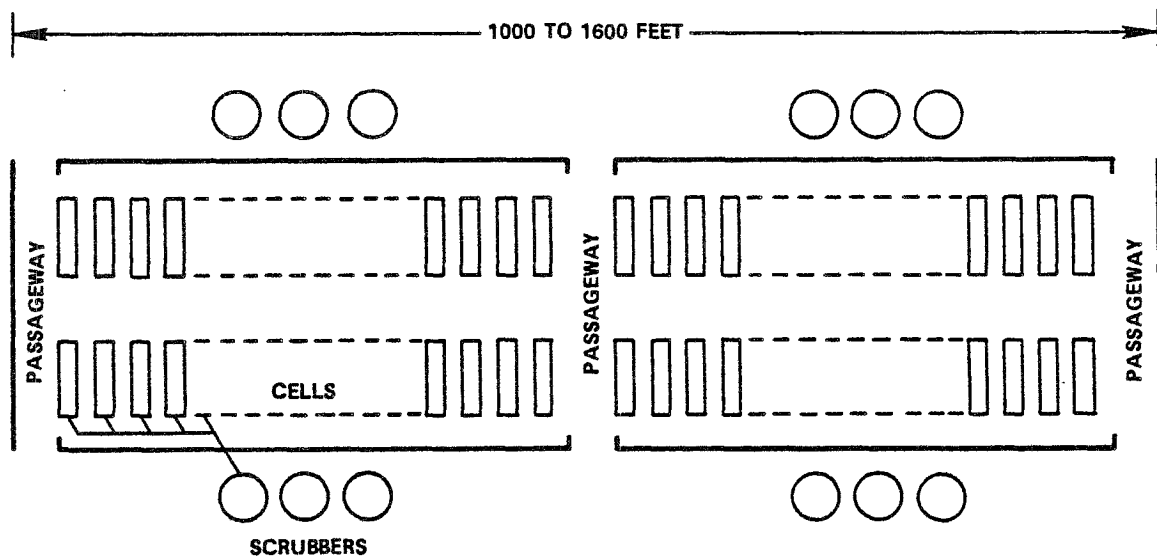


Figure 4-3. Typical plan view of potroom.10

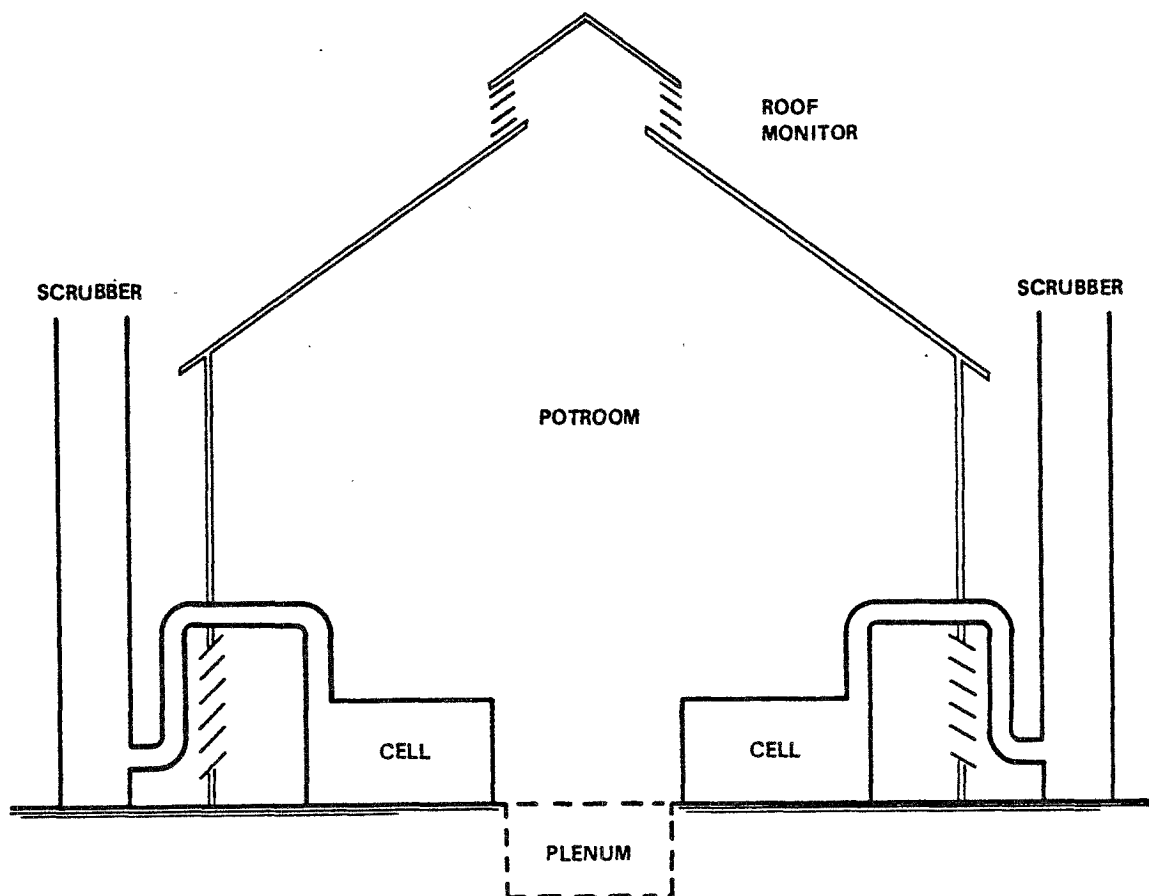


Figure 4-4. Typical elevation view of potroom.11

runs the length of the building and serves the important function of releasing the heat lost from the pots to the building air, thus maintaining workable conditions around the pots. Outside air may be introduced to the potroom through side vents, or forced through a central floor plenum, or both.

The "process" of primary aluminum reduction is essentially one of materials handling. It can be shown schematically as a flow diagram such as Figure 4-5. The true difference in the various process modifications used by the industry lies in the type of reduction cell used. Three types of reduction cells or pots are used in the United States: prebake (PB), horizontal stud Soderberg (HSS), and vertical stud Soderberg (VSS). Both Soderberg cells employ continuously formed consumable carbon anodes where the anode paste is baked by the energy of the reduction cell itself. The prebake cell, as indicated by its name, employs a replaceable, consumable carbon anode, formed by baking in a separate facility called an anode bake plant, prior to its use in the cell.

The preparation of anode materials is usually an ancillary operation at the reduction plant site. Figure 4-6 is a typical flow diagram for the preparation of prebake anodes. In the carbon plant, or "green mill", coke is crushed and sized; cleaned, returned anode butts are crushed; and both are mixed together with pitch and molded to form self-supporting green anode blocks. Figure 4-6 shows solid coal tar pitch moving to a crusher. The pitch may not be coal tar, and it may be received and handled as a liquid. The green anode blocks are fired and baked in a pit baking furnace, or ring furnace. Subsequently, a steel or iron electrode is bonded into a preformed hole

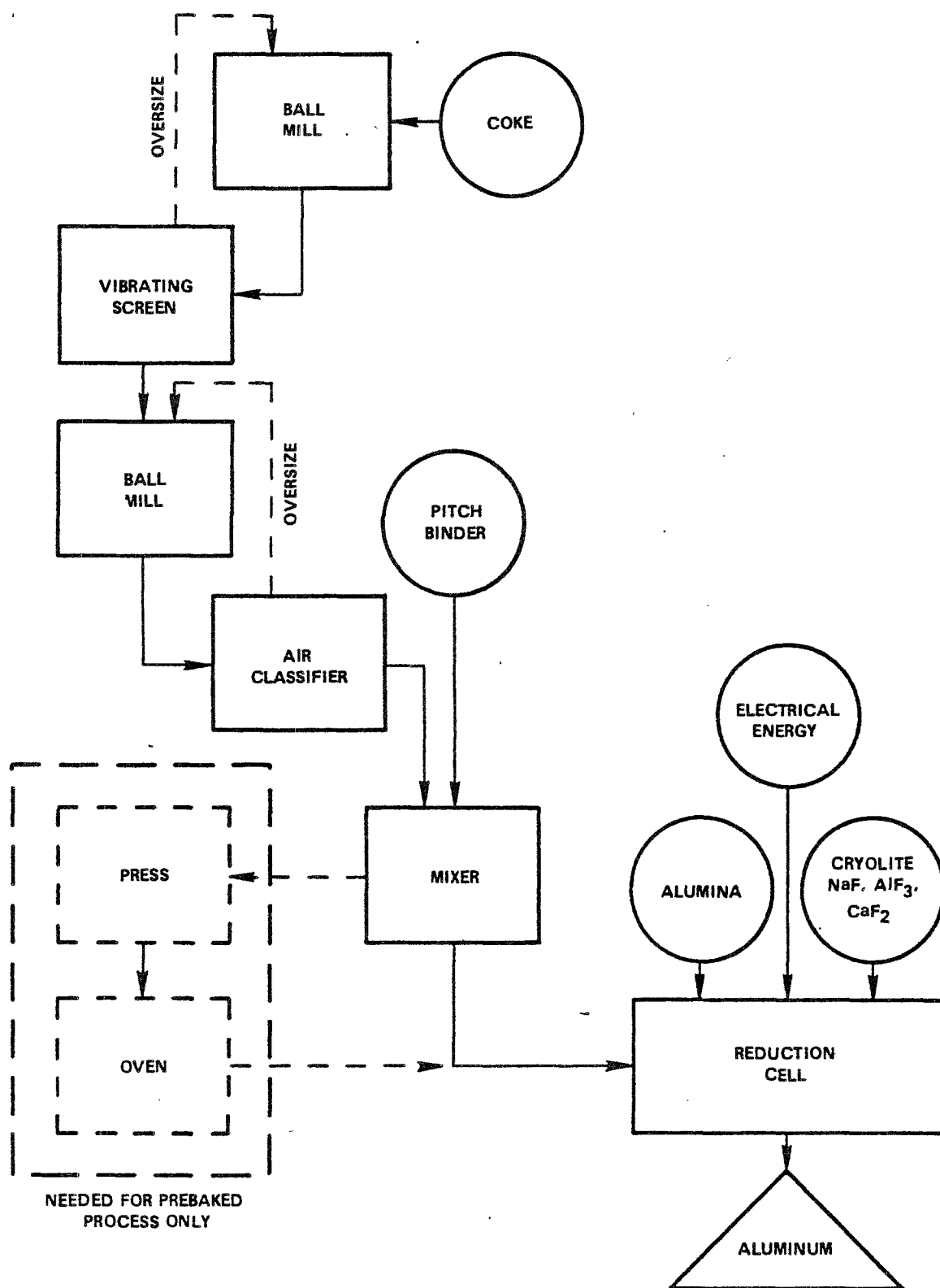


Figure 4-5. General flow diagram for primary aluminum reduction.¹²

in each block. The electrode serves as an electrical connector and holds the anode in place in the bath. The ring furnace operation comprises the anode bake plant. A second type of furnace, the tunnel kiln, has also been developed for baking anodes.

The preparation of Soderberg anode material is similar to that for prebake cells, except that the pitch is always liquid, the anode paste is not molded and baked prior to cell usage, and no anode material is returned from the cells to the carbon plant.

Since the potrooms housing the reduction cells and the prebake anode bake plant are the facilities affected by the standards of performance for new primary aluminum plants and attendant State plans for controlling existing plants, the different cell types and the bake plant merit further consideration. Process items specific to each are discussed in the following sections.

4.3 SODERBERG CELLS^{18,19,20}

There are two types of Soderberg cells, each having a single large carbon anode, but differing in the method of anode bus connection to the anode mass. In both the vertical stud Soderberg (VSS) and the horizontal stud Soderberg (HSS), a green anode paste is fed periodically into the open top of a rectangular steel compartment and baked by the heat of the cell to a solid coherent mass as the material moves down the casing.

In both types of Soderberg cells, the in-place baking of the anode paste results in the release of hydrocarbon fumes and volatiles derived from the pitch binder of the paste mixture. These products are a component of the Soderberg cell emissions and are essentially absent from those of the prebake cells. If not removed from the gas stream, the pitch components will condense in and plug subsequent ductwork and emission control devices.

Although the Soderberg cells required more electrical energy to produce a given weight of metallic aluminum, and create problems in emission control, they were acclaimed initially because they did away with the need for a separate anode manufacturing facility.

Partially because the volatile pitch components can condense in the ductwork and the control device, and partially because of the problems of simultaneously controlling fluorides and organic emissions, any economic advantage of the Soderberg systems is diminishing and the trend appears to be toward the prebake cell.

Furthermore, although prebake cells may be center-worked or side-worked, the use of a single large carbon anode requires that both types of Soderberg cells be side-worked. As will be discussed in Section 6.1, center-worked cells lend themselves to more efficient hooding and hence more efficient emission control.

4.3.1 Vertical Stud Reduction Cells

Figure 4-8 shows a sectional view of a typical vertical stud Soderberg reduction cell. The anode casing is stationary, the electrical connection from the studs to the bus bar is rigid, and

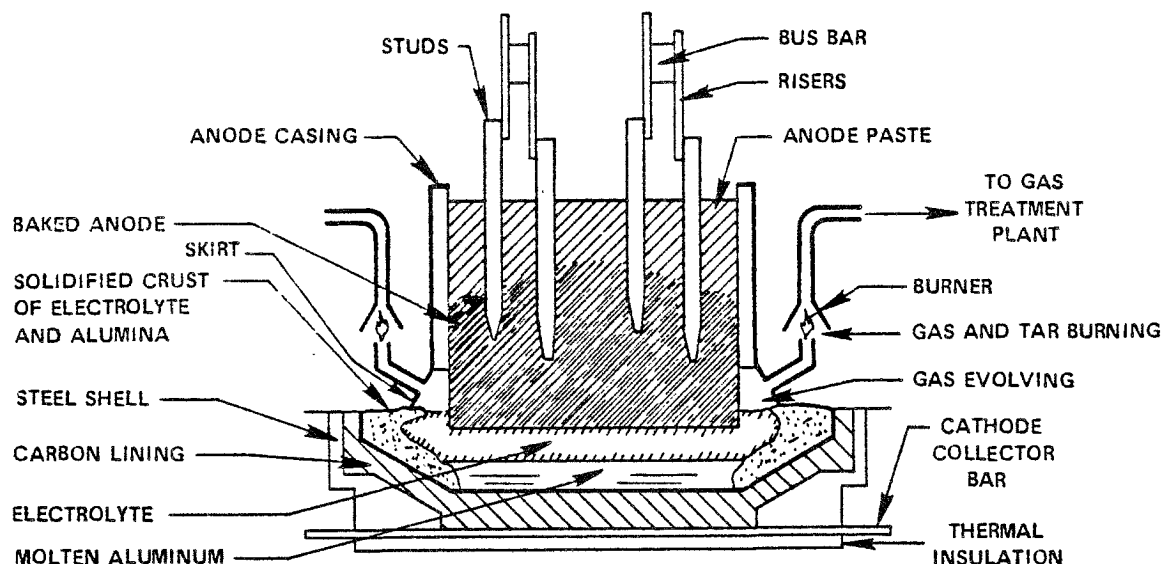


Figure 4-8. Details of vertical stud Soderberg reduction cell.¹⁸

the steel current-carrying studs project vertically through the unbaked paste portion and into the baked portion of the anode. As the anode is consumed and moves down the casing, the bottommost studs are periodically extracted before they become exposed to the bath at the bottom of the anode.

The stationary anode casing and the projection of the studs through the top of the anode allow the installation of a gas collection skirt between the anode casing and the bath surface. The gases are ducted to integral gas burners where the hydrocarbon tars are burned to gaseous fractions that do not interfere with the operation of subsequent pollutant removal equipment. Maintenance of the skirt system is a problem, however. Irregularities in cell operation can extinguish the burner flame, and the skirts may melt or be deformed by the heat. Pilot lights can help ensure that the burners stay lighted.